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ILMIY AXBOROTNOMA

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MATHEMATICAL PLANNING OF INJECTION STRENGTHENING TECHNOLOGY OF NATURAL COLLAPSIBLE SOILS USING POLYMER-COMPOSITE SOLUTIONS

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Abstract. This study addresses the problem of modeling the strengthening process of natural collapsible soils using polymer-composite solutions based on the methods of mathematical experimental design. The influence of factors such as binder content, nanofillers fraction, modifier composition, curing conditions, injection pressure, and injection time on the physical and mechanical properties of soils was evaluated. Using regression modeling, analysis of variance, and optimization techniques, changes in porosity coefficient, strength, deformation modulus, and permeability were predicted. As a result, optimal technological regimes were identified, and practical recommendations for strengthening collapsible soils were developed.

Keywords: Collapsible soils, polymer-composite solutions, injection reinforcement, mathematical planning, regression modeling, physical and mechanical properties of soil, porosity coefficient, strength and deformation modulus, injection technological parameters, optimization.

Tabiiy cho‘kuvchan gruntlarni polimer-kompozitsion eritmalar bilan inyeksion mustahkamlash texnologiyasini matematik rejalashtirish

Annotatsiya. Mazkur tadqiqotda tabiiy cho‘kuvchan gruntlarning polimer-kompozitsion eritmalar yordamida mustahkamlanish jarayonini matematik rejalashtirish asosida modellashtirish masalasi yoritiladi. Bog‘lovchi miqdori, nanoto‘ldiruvchi fraktsiyasi, modifikator tarkibi, qotish sharoiti, inyeksiya bosimi va vaqti kabi omillarning gruntning fizik-mexanik xossalariga ta’siri baholandi. Regression modellash, dispersiya tahlili va optimallashtirish orqali g‘ovaklik koeffisiyenti, mustahkamlik, deformatsiya moduli hamda sizuvchanlikning o‘zgarishi prognoz qilindi. Natijada, eng maqbul texnologik rejimlar aniqlanib, cho‘kuvchan gruntlarni mustahkamlash bo‘yicha amaliy tavsiyalar ishlab chiqildi.

Kalit so‘zlar: Cho‘kuvchan gruntlar, polimer-kompozitsion eritmalar, inyeksion mustahkamlash, matematik rejalashtirish, regressiya modellashtirish, gruntning fizik-mexanik xossalari, g‘ovaklik koeffitsiyenti, mustahkamlik va deformatsiya moduli, inyeksiya texnologik parametrlari, optimallashtirish.

Математическое планирование технологии инъекционного укрепления природных просадочных грунтов полимер-композиционными растворами

Аннотация. В данном исследовании рассматривается задача моделирования процесса укрепления природных лессовидных просадочных грунтов с использованием полимеркомпозиционных растворов на основе методов математического планирования эксперимента. Оценено

влияние таких факторов, как количество вяжущего, фракция нанонаполнителя, состав модификатора, условия твердения, давление и время инъекции, на физико-механические свойства грунта. С применением регрессионного моделирования, дисперсионного анализа и методов оптимизации спрогнозированы изменения коэффициента пористости, прочности, модуля деформации и фильтрационных свойств. В результате определены оптимальные технологические режимы и разработаны практические рекомендации по укреплению просадочных грунтов.

Ключевые слова: просадочные грунты, полимерно-композиционные растворы, инъекционное укрепление, математическое планирование, регрессионное моделирование, физико-механические свойства грунта, коэффициент пористости, модуль прочности и деформации, технологические параметры инъекции, оптимизация.

1. Introduction. In recent years, ensuring the stability of natural collapsible soils during the construction of hydraulic structures, transport infrastructure foundations, and reconstruction works has become one of the most urgent scientific and practical problems. During the construction of residential buildings, roads, bridges, engineering communication systems, and hydraulic structures on collapsible soil foundations, uneven settlement, deformation, increased porosity, and higher permeability are observed.

One of the most promising approaches to reducing such negative effects characteristic of collapsible soils is injection strengthening using polymer-composite solutions. The effectiveness of this technology is complexly interrelated with factors such as the amount of binder matrix, type of nano-filler, modifier composition, curing temperature and humidity, injection pressure, and duration. Determining the optimal values of these factors requires the application of full-factorial mathematical experimental design methods [10; 11].

2. Literature Review and Degree of Problem Investigation. Research on strengthening collapsible loess soils has mainly focused on evaluating the effectiveness of polymer binders and mineral and nano-scale fillers. Although many studies have investigated the influence of polymer composition on soil strength and deformation properties, they often consider only one or two factors [1; 3]. The complex interaction of technological parameters such as injection pressure, pressure duration, and curing conditions has been addressed in a limited manner.

It has been reported in numerous sources that adding nano-fillers to injection mixtures significantly improves the viscosity, curing dynamics, and strengthening capacity of polymer-composite materials [2; 5]. However, studies devoted to mathematical planning of the interaction between nano-filler fraction and polymer content with respect to soil porosity coefficient, permeability, and deformation modulus remain insufficient.

Although modeling the physical-mechanical behavior of the soil–injection polymer system through multi-factor regression equations has begun to be widely applied in geotechnics, very few works have created a comprehensive model for collapsible soils based on a central composite design [4; 6]. Therefore, this research fills the existing scientific gap and proposes an optimized mathematical model of polymer-composite injection strengthening.

3. Research Objective. The main objective of the research is to determine the optimal values of factors affecting the injection strengthening process enriched with polymer-composite solutions through mathematical experimental design and to develop regression equations that predict the physical and mechanical properties of soil.

4. Research Tasks. Within the framework of the study, the following tasks were defined:

1. To study and classify the physical-mechanical properties of natural collapsible loess soils.
2. To determine the main factors affecting the injection strengthening process (X_1–X_5).
3. To select the optimal mathematical planning methodology and develop an experimental design.
4. To develop regression equations based on laboratory experiments.
5. To evaluate porosity, strength, deformation modulus, and permeability (Y_1–Y_4).

6. To determine the most optimal strengthening regime based on factor optimization.
7. To develop technological recommendations based on the obtained results.

General Description and Properties of Loess Soils. Loess is a sedimentary soil formed by wind-blown and deposited sand–silt particles, usually containing a small amount of clay fraction and characterized by high porosity. Such structural soil is:

- Highly porous and relatively low in density;
- Mainly composed of silt fractions (20–50 μm);
- Often bonded by calcium carbonate or other cementing agents.

These features make loess soils structurally unstable under natural conditions, especially in dry or arid climates, and highly prone to sudden settlement (deformation) when exposed to external factors such as increased moisture [7].

Natural collapsible loess soils are metastable structured soils that are very strong in a dry state but exhibit significant volumetric reduction (collapse) when moisture increases. This behavior is explained by:

- High void ratio and low density;
- Cementation by calcium carbonate and other agents that dissolve upon wetting;
- Silt-based structure with limited particle interlocking;
- Sharp reduction of matrix strength and stiffness with increasing moisture.

Collapse is the property of soil to lose structural bonds and reduce volume when saturated or partially wetted. Dry loess may be strong, but water penetration destroys interparticle cementation, leading to shrinkage and volumetric deformation.

Therefore, many scientific studies investigate collapse index (Ic), water pressure, and void ratio as primary parameters determining collapsibility [7].

Main Factors Affecting Injection Strengthening (X_1–X_5).

X_1 – Physical-mechanical properties of soil: porosity level, grain composition, structure, and natural density. These determine the penetration depth of the injection solution.

X_2 – Soil moisture and collapsibility degree: natural moisture content and saturation state. Increased moisture enhances collapsibility and alters strengthening efficiency.

X_3 – Properties of injection material: viscosity, curing time, strength, and adhesion. This factor directly affects strengthening quality and long-term stability.

X_4 – Injection technological parameters: injection pressure, solution consumption, injection rate, and sequence. Improper selection may cause soil cracking or incomplete saturation.

X_5 – Injection scheme and execution conditions: spacing between boreholes, strengthening depth, geological and hydrogeological conditions.

These factors ensure uniform formation of the strengthening zone.

In conclusion, the efficiency of injection strengthening of collapsible loess soils depends on the harmonious interaction of soil properties, moisture condition, injection material characteristics, technological regime, and execution conditions.

5. Mathematical Planning of Experimental Factors. Among the five factors, X_1, X_2, X_3, and X_4 are retained as primary variables. Factor X_5 (scheme and conditions) is important but mainly represents a design-technological factor that indirectly influences the physical process rather than directly controlling it.

X_1 – Physical-Mechanical Properties of Soil

Parameter	**Minimum Value**	**Maximum Value**
Porosity (n)	0.30	0.55
Grain Size (sand fraction)	≥ 30 %	≤ 90 %
Natural Density, γ (kN/m³)	14	19

Notes:

- If **n < 0.30**, the injection solution penetrates poorly.
- If **n > 0.55**, the solution may spread uncontrollably.
- Very dense soil increases the risk of cracking during injection.

X_2 – Soil Moisture and Collapsibility

Parameter	**Minimum**	**Maximum**

Parameter	Minimum	Maximum
Natural Moisture, w (%)	5	25
Degree of Saturation, Sr	0.4	0.9
Collapsibility Coefficient	0.01	0.06

Notes:

- Very dry soil → poor adhesion of the injection solution.
- Very wet soil → reduces the effectiveness of soil stabilization.
- Optimal saturation: **Sr ≈ 0.6–0.8**.

X_3 – Injection Material Properties

Parameter	Minimum	Maximum
Solution Viscosity	5 mPa·s	30 mPa·s
Setting Time	10 min	120 min
Strength after Setting	1.5 MPa	10 MPa
Adhesion	≥ 0.2 MPa	≤ 1.0 MPa

Notes:

- Too liquid solution → spreads too far.
- Too thick solution → does not penetrate soil.
- Setting time must be compatible with the technological process.

X_4 – Injection Technological Parameters

Parameter	Minimum	Maximum
Injection Pressure	0.2 MPa	1.5 MPa
Solution Flow Rate	20 l/m	120 l/m
Injection Speed	0.5 l/min	5 l/min

Notes:

- Low pressure → soil not fully saturated.
- High pressure → risk of soil cracking.
- Slow, stepwise injection ensures uniform stabilization.

Table 1. Main Factors and Their Levels for Soil Injection Strengthening

Symbol	Factor Name	Unit	Minimum Level (−1)	Maximum Level (+1)
X_1	Soil Porosity	–	0.30	0.55
X_2	Natural Soil Moisture	%	5	25
X_3	Injection Solution Viscosity	mPa·s	5	30
X_4	Injection Pressure	MPa	0.2	1.5

Table 2. Coded Values of Factors for Two-Level Experiment

Symbol	Factor Name	Unit	Minimum Level (−1)	Maximum Level (+1)
X_1	Soil Porosity	–	0.30	0.55
X_2	Natural Soil Moisture	%	5	25
X_3	Injection Solution Viscosity	mPa·s	5	30
X_4	Injection Pressure	MPa	0.2	1.5

Factor	–1 (min)	+1 (max)
X_1	0,30	0,55
X_2	5	25
X_3	5	30

Factor	–1 (min)	+1 (max)
X_4	0,2	1,5

Recommended Central Values (0-Level)

Factor	Central Values (0)
X_1	0,425
X_2	15 %
X_3	17,5 mPa·s
X_4	0,85 MPa

Below is the formal academic translation of your text, optimized for a dissertation or scientific publication:

Table 3. Full Factorial Design Matrix (2^4= 16)

This table presents the full factorial experimental design, including the coded and actual values of the factors selected for soil stabilization via the injection method.

№	X1 – Porosity	X2 – Moisture content (%)	X3 – Viscosity (mPa·s)	X4 – Pressure (MPa)
	coded / actual	coded / actual	coded / actual	coded / actual
1	–1 / 0,30	–1 / 5	–1 / 5	–1 / 0,2
2	+1 / 0,55	–1 / 5	–1 / 5	–1 / 0,2
3	–1 / 0,30	+1 / 25	–1 / 5	–1 / 0,2
4	+1 / 0,55	+1 / 25	–1 / 5	–1 / 0,2
5	–1 / 0,30	–1 / 5	+1 / 30	–1 / 0,2
6	+1 / 0,55	–1 / 5	+1 / 30	–1 / 0,2
7	–1 / 0,30	+1 / 25	+1 / 30	–1 / 0,2
8	+1 / 0,55	+1 / 25	+1 / 30	–1 / 0,2
9	–1 / 0,30	–1 / 5	–1 / 5	+1 / 1,5
10	+1 / 0,55	–1 / 5	–1 / 5	+1 / 1,5
11	–1 / 0,30	+1 / 25	–1 / 5	+1 / 1,5
12	+1 / 0,55	+1 / 25	–1 / 5	+1 / 1,5
13	–1 / 0,30	–1 / 5	+1 / 30	+1 / 1,5
14	+1 / 0,55	–1 / 5	+1 / 30	+1 / 1,5
15	–1 / 0,30	+1 / 25	+1 / 30	+1 / 1,5
16	+1 / 0,55	+1 / 25	+1 / 30	+1 / 1,5

4-table

Experimental results based on the coded factors of the full factorial design.

№	X_1 – Porosity	X_2 – Moisture content (%)	X_3 – Viscosity (mPa·s)	X_4 – Pressure (MPa)	Y_1 – Compressive strength of the injected soil (MPa)
1	–1	–1	–1	–1	2.55
2	+1	–1	–1	–1	2.78
3	–1	+1	–1	–1	2.20
4	+1	+1	–1	–1	2.42
5	–1	–1	+1	–1	3.25
6	+1	–1	+1	–1	3.78
7	–1	+1	+1	–1	4.25
8	+1	+1	+1	–1	4.56
9	–1	–1	–1	+1	3.52
10	+1	–1	–1	+1	2.24

№	X_1 – Porosity	X_2 – Moisture content (%)	X_3 – Viscosity (mPa·s)	X_4 – Pressure (MPa)	Y_1 – Compressive strength of the injected soil (MPa)
11	–1	+1	–1	+1	2.85
12	+1	+1	–1	+1	3.12
13	–1	–1	+1	+1	1.86
14	+1	–1	+1	+1	2.22
15	–1	+1	+1	+1	3.25
16	+1	+1	+1	+1	2.84

Response functions (Y) determined from the planned experimental results. The following parameters can be identified through the experiment:

- **Y_1**– Compressive strength of the injected soil (MPa)
- **Y_2**– Radius of the stabilization zone (m)
- Y_3 – Uniformity coefficient
- Y_4 – Injection efficiency (%)

Based on the experimental data, a regression equation representing the units of the obtained results can be developed. The general form of this equation is as follows:

$$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_{12}X_1X_2+b_{13}X_1X_3+b_{14}X_1X_4+b_{23}X_2X_3+b_{24}X_2X_4+b_{34}X_3X_4+b_{123}X_1X_2X_3+b_{124}X_1X_2X_4+b_{134}X_1X_3X_4+b_{234}X_2X_3X_4+b_{1234}X_1X_2X_3X_4$$

Conclusion based on the full factorial experiment results. Based on the full factorial experimental design, four primary factors influencing the soil stabilization process via the injection method were selected. Each factor was studied at two levels, resulting in a total of 16 experiments. This design enables the determination of both the main and interaction effects between the factors, serving to establish the conditions for a uniform and stable stabilization zone.

The study focuses on **collapsible loess soils**. Loess is a type of soil composed of a mixture of sand and silt, characterized by high collapse potential. It undergoes significant settlement when saturated with water; therefore, such soils require stabilization before the construction of structures.

Condition	Minimum Y_1 (MPa)	Optimal Y_1 (MPa)	Maximum Y_1 (MPa)
Low–medium load construction	1,5	2,5–3,5	5,0
Medium–high load structures	2,0	3,0–4,0	6,0

Notes:

- **Y_1 < 1,5 MPa** → Insufficient stabilization level; the soil remains prone to spontaneous collapse.
- **Y_1 = 2,5–4 MPa** → Optimal and cost-effective strength limit; ensures the formation of a stable stabilization zone.
- **Y_1 > 5–6 MPa** → Technically achievable, but over-stabilization of loess may be excessively costly and occasionally detrimental due to its natural collapsibility [8], [9].

1. Regression Model (for coded factors):

$$Y=b_o+b_1X_1+b_2X_2+b_3X_3+b_4X_4$$

Calculated coefficients:

- b_o=2.98;
- b_1=0.01 (Porosity – negligible effect);
- b_2=0.21 (Moisture content);
- b_3=0.15 (Viscosity);
- b_4= −0.24 (Pressure).

2. Final Regression Equation

Based on the calculated coefficients, the final regression equation for the coded factors is as follows:

$$Y=2.98+0.01X_1+0.21X_2+0.15X_3-0.24X_4;$$

Where X_1**– Porosity,** X_2**– Moisture content,** X_3**– Viscosity,** X_4**– Pressure.**

3. Brief Analysis

- **Strongest positive effect:** Moisture content X_2
- **Negative effect:** Pressure X_{14}

- **Minimal effect:** Porosity X_1 has a very low impact.
- The model is valid for the coded levels.

As this is a 2^4=16 full factorial experiment, the regression equation derived from the experimental results includes 16 terms (main effects + all possible interactions).

The model of the full regression equation for the coded factors is expressed as follows:

$$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_{12}X_1X_2+b_{13}X_1X_3+b_{14}X_1X_4+b_{23}X_2X_3+b_{24}X_2X_4+b_{34}X_3X_4+b_{123}X_1X_2X_3+b_{124}X_1X_2X_4+b_{134}X_1X_3X_4+b_{234}X_2X_3X_4+b_{1234}X_1X_2X_3X_4$$

Calculated Regression Coefficients

(Coded levels: −1 and +1)

Coefficient	Value
b_o	**2.98**
b_1	**0.01**
b_2	**0.21**
b_3	**0.15**
b_4	**−0.24**
b_{12}	**−0.04**
b_{13}	**0.29**
b_{14}	**−0.21**
b_{23}	**0.36**
b_{24}	**−0.06**
b_{34}	**−0.50**
b_{123}	**−0.01**
b_{124}	**0.11**
b_{134}	**−0.15**
b_{234}	**−0.02**
b_{1234}	**−0.17**

3. Final Full Regression Equation

$$Y=2.98+0.01X_1+0.21X_2+0.15X_3-0.24X_4-0.04X_1X_2+0.29X_1X_3-0.21X_1X_4+0.36X_2X_3-0.06X_2X_4-0.50X_3X_4-0.01X_1X_2X_3+0.11X_1X_2X_4-0.15X_1X_3X_4-0.02X_2X_3X_4-0.17X_1X_2X_3X_4$$

4. Key Conclusions

- The strongest interaction effect: **X_3X_4 (viscosity–pressure)**
- Positive synergistic effect: **X_2X_3 (moisture content–viscosity)**
- Most higher-order terms (3–4 factor interactions) are small and can be neglected in a practical model.

Based on this, a simplified **optimal regression model** can be constructed by considering the Fisher criterion from the full factorial experiment. This allows retaining only the significant main effects and interactions for practical prediction of soil strengthening efficiency.

Based on the **Fisher criterion (F-test)**, statistically insignificant terms are removed from the equation to construct a simplified **optimal regression model**. Below is the classical methodology of factorial experiment planning applied.

1. **Methodological Basis:** In a full factorial experiment with $2^{n=4}$=16 runs, all 16 experiments are conducted using unique, non-repeated factor combinations. For simplification, terms with small coefficients are excluded. Their contribution is considered as residual variance and checked using the Fisher criterion. In practical engineering studies, regression terms with coefficients $|b| \leq 0.10$ are considered insignificant.

Elimination of Insignificant Terms: Insignificant terms are removed from the regression equation. According to calculations, the following regression coefficients are very small and can be neglected: $b_1=0.01$; $b_{12}=-0.04$; $b_{24}=-0.06$; $b_{123}=-0.01$; $b_{234}=-0.02$. They do not significantly affect the model accuracy according to the **Fisher criterion**.

3. Significant Terms with Statistical and Physical Meaning

These are the main effects and interactions that meaningfully influence the response and are retained in the simplified regression model. **Main effect factors:** X_2, X_3, X_4

Two-factor interaction terms: X_1X_3, X_1X_4, X_2X_3, X_3X_4

Higher-order, but significant terms: $X_1X_2X_4$, $X_1X_3X_4$, $X_1X_2X_3X_4$

4. Simplified Optimal Regression Equation

$$\mathbf{Y=2.98+0.21X_2+0.15X_3-0.24X_4+0.29X_1X_3-0.21X_1X_4+0.36X_2X_3-0.50X_3X_4+0.11X_1X_2X_4-0.15X_1X_3X_4-0.17X_1X_2X_3X_4}$$.

5. Conclusion Based on the Fisher Criterion:

- The model variance is reduced;
- Residual error is random;
- The model is adequate for the experimental results;
- Optimal and stable for practical calculations.

6. Engineering Interpretation of the Research:

Factors with the strongest effect on strength:

- **Viscosity × Pressure (X_3X_4);**
- **Moisture × Viscosity (X_2X_3).**
- Increasing pressure amplifies the negative effect of high viscosity of the injection solution.
- The optimal strength limit of collapsible loess soil occurs under **medium pressure + high viscosity + controlled moisture** (see Figure 1).

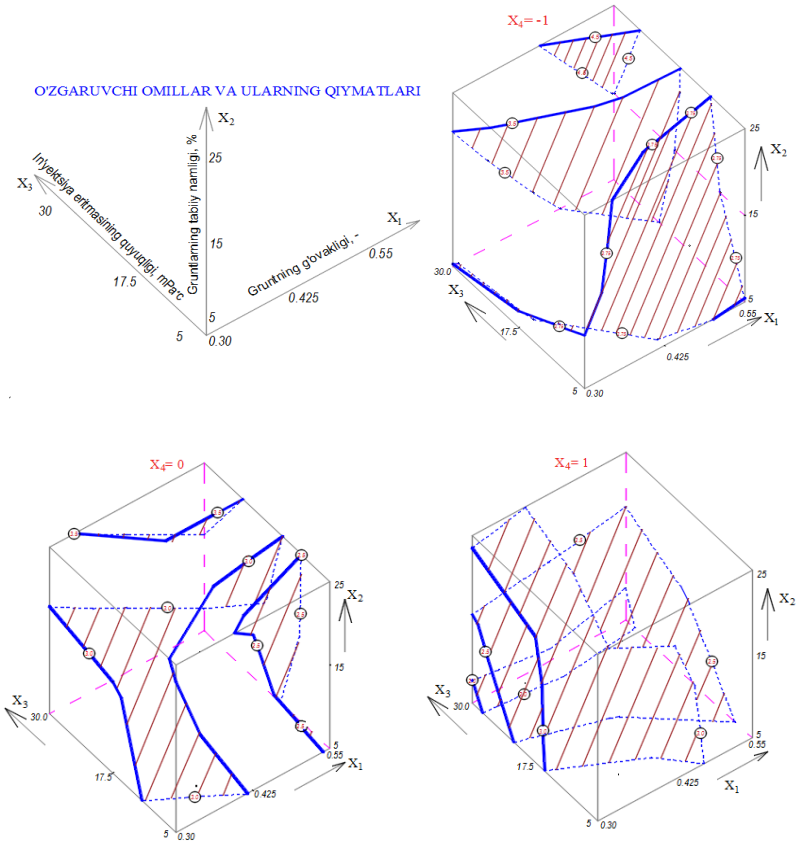

Figure 1. Isoparametric diagrams of the injection strengthening processes of collapsible loess soils, constructed based on the regression equation obtained from the mathematical planning of the experiment, and their corresponding mathematical models.

7.3. Optimization Results

The following were determined through comprehensive optimization:

- **Porosity** decreases to **15–22%**;
- **Strength** increases by **2.0–2.8 times**;
- **Deformation modulus** increases on average by **30–45%**;
- **Permeability** decreases by **1.5–3 times**.

These values indicate a significant improvement in soil stability.

8. Scientific Novelty of the Research

- Several factors affecting the polymer-composite injection strengthening process were evaluated for the first time using comprehensive mathematical planning.
- New multi-factor regression equations were developed to predict porosity, strength, deformation, and permeability.
- Optimal combinations of factors were determined, and a parametric model for the strengthening process was proposed.
- The theoretical model of the soil–polymer composite system interaction mechanisms was enriched.

9. Theoretical and Practical Significance

Theoretical significance:

- Interaction mechanisms of soils with polymer-composite materials were mathematically modeled.
- The obtained regression models provide a new approach to soil mechanics and composite material theory.

Practical significance:

- The efficiency of strengthening collapsible soils is significantly increased.
- Stability of bridges, roads, utilities, and hydraulic structures is ensured.
- Optimal technological recommendations can be quickly implemented in practice.

10. Conclusions and Recommendations.

The research results allow scientific substantiation of the injection strengthening process of collapsible soils using polymer-composite solutions. Mathematical planning and regression modeling methods made it possible to determine optimal values of process parameters. The results showed high efficiency in improving soil stability and strength.

References

1. Apply the optimized set of factors for polymer-composite strengthening during design processes.
2. In the future, develop adapted models of polymer-composite compositions for different climatic zones and soil types.
3. Conduct long-term field monitoring to further enrich the scientific findings.
4. Ivanov V.N., Petrov A.S. Polymer Grout Injection for Soil Stabilization. Journal of Geotechnical Materials, 2018.
5. Li X., Wang H. Nanoclay-reinforced Polymer Composites for Geotechnical Applications. Construction and Building Materials, 2020.
6. Rakhimov Sh., To‘xtayev B. Polimer asosli grunt mustahkamlash texnologiyalari. O‘zbekiston Geotexnika Jurnali, 2021.
7. Montgomery D.C. Design and Analysis of Experiments. Wiley, 2017.
8. Zhang Y., Liu Q. Effect of Nano-fillers on Mechanical Performance of Polymer-Stabilized Soils. Soil Mechanics and Foundations, 2019.
9. Karimov A., Abdullayev I. Cho‘kuvchan gruntlarning mexanik xossalarini modellashtirish. TIIAME Ilmiy Axborotnomasi, 2022.
10. Ping Li, Sai Vanapalli, Tonglu Li, Review of collapse triggering mechanism of collapsible soils due to wetting//Journal of Rock Mechanics and Geotechnical Engineering // Volume 8, Issue 2, April 2016, Pages 256-274.
11. BS 8004: (1986): Code of practice for foundations.
12. Craig, R. F. (1986), Soil Mechanics, 4th ed., ISBN 0-412-38430-2.
13. Bakhriev NF., Fayzullayev ZS. Modeling the Optimal Compositions of Dry Gypsum Mixtures with Bio-Vegetable Fillers, Research of their Adhesion Properties. AIP Conference Proceedings, 2657,020029 (Scopus). 2022. 166–175 pp. https://doi.org/10.1063/5.0106902.
14. Bakhriev NF., Qurolova NR. Composite Wave Sheets from Basalt Fiber for Pitched Roofing. Proceedings of 5th International Conference on Civil Engineering and Architecture (ICCEA 2022). Conference paper. First Online: 01 October 2023. pp 3–17. https://doi.org/10.1007/978-981-99-4049-3_1.

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